Effect of Lime and Fly ash on Cation Exchange Capacity (CEC) and Unconfined Compressive Strength (UCS) of Soils

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CERTIFICATE

This is to certify that the thesis entitled **"Effect of lime and fly ash on Cation Exchange Capacity (*CEC*) and Unconfined Compressive Strength (*UCS*) of Soils"** being submitted by **Khan Mohammedali Asgarali** bearing Roll No. 213CE1038 towards partial fulfilment of the requirement to award the degree of Master of Technology in Geotechnical Engineering at Department of Civil Engineering, National Institute of Technology Rourkela is a record of bonafide work carried out by him under my guidance and supervision. It is further certified that the contents presented in this thesis has not been submitted elsewhere for the award of any degree or diploma.

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ABSTRACT

The utilization of fly ash in India varies between 50-60% and the rest are disposed in ash ponds. The fly ash which are utilized for reclamation of low lying areas or which are used in geotechnical engineering application has the tendency of leaching the heavy metal pollutants and thus polluting the groundwater, surface water and surrounding soil. Also the discharge of effluents from waste water treatment plants may lead to pollution of the ground water. If these ground water pollution can be controlled by increasing the Cation Exchange Capacity of the sub soil through application of any of the additives such as lime, fly ash, cement etc. which also leads to increase in strength of the soil then that additive would be favourable in case of geotechnical projects where ground water pollution is of great concern.

The present work aims to find the effect of additives namely Lime and Fly ash on Cation Exchange Capacity (*CEC*), Compaction characteristics, and Unconfined Compressive Strength (*UCS*) of two soils. The two soils used in this study are Sandy Clay (*SC*) and Low Plasticity Clay (*CL*). First the soils were mixed individually with varying contents of lime and fly ash to find out their effects on Cation Exchange Capacity (*CEC*) and for conducting Light compaction test to find the compaction characteristics. Then the treated soil samples compacted at Optimum Moisture Content (*OMC*) and Maximum Dry Density (*MDD*) were tested for Unconfined Compressive Strength (*UCS*) at different Curing periods.

From the experimental results obtained, it is observed that for both soils, Cation Exchange Capacity (*CEC*) decreases more with increase in fly ash content than with Lime content. Also Optimum Moisture Content (*OMC*) increases and Maximum Dry density (*MDD*) decreases with increase in Lime and Fly ash content for both the soil samples. The Unconfined Compressive Strength (*UCS*) increases with lime and fly ash content up to a certain limit beyond which further increase in lime and fly ash content does not increase the Unconfined Compressive Strength (*UCS*). The Unconfined Compressive Strength (*UCS*) increases more with increase in Lime content than by increase in fly ash content. The Unconfined Compressive Strength (*UCS*) increases with curing time.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CEC	Cation Exchange Capacity
SSA	Specific Surface Area
LL	Liquid Limit
PL	Plastic Limit
SL	Shrinkage Limit
PI	Plasticity Index
EGME	Ethylene Glycol Monoethyl Ether
TOC	Total Organic Carbon
OC	Organic Carbon
CF	Clay Fraction
MFSI	Modified Free Swell Index
OM	Organic Matter
CBR	California Bearing Ratio
OMC	Optimum Moisture Content
MDD	Maximum Dry Density
SC	Sandy Clay
CL	Low Plasticity Clay
D_{10}	Particle size finer than 10% of total mass
D_{30}	Particle size finer than 30% of total mass
D_{60}	Particle size finer than 30% of total mass
C_u	Coefficient of Uniformity
C_c	Coefficient of Curvature
UCS	Unconfined Compressive Strength
OLC	Optimum Lime Content

1. INTRODUCTION

In India, there is an increase in the number and capacity of the thermal power plants because of the increase in demand for electricity. Most of these thermal power plants use coals which are of inferior quality. These inferior quality coals produce huge amount of fly ash. According to the Central Electricity Authority (CEA) report on fly ash generation and utilization, 61 percent and 57.63 percent of the fly ash produced was utilized during the year 2012-2013 and 2013-2014 respectively. Thus the utilization of fly ash in India varies between 50-60% and rests are disposed in ash ponds. These disposed fly ash and even the fly ash which are utilized for reclamation of low lying areas has the tendency of leaching the heavy metal pollutants and thus polluting the groundwater. This ground water pollution can be controlled by increasing the Cation Exchange Capacity (*CEC*) of sub soil through application of additives such as lime, fly ash, cement etc. so that the individual soil colloids can hold the pollutant cations at their exchange sites.

So, if any of the additives which doesn't affects or increases the Cation Exchange Capacity (*CEC*) of the soil along with increasing the strength of the soil then the additive would be beneficial in case of geo-environmental projects.

The surface properties of the fine grained soil may greatly influence their physical and chemical properties. Fine grained soils differ in their surface properties like Cation Exchange Capacity (*CEC*) and Specific Surface Area (*SSA*) mainly because of the type and amount of different clay minerals, differences in grain size distribution. Cation Exchange Capacity (*CEC*) is defined as the capacity of a soil to hold a certain amount of exchangeable ions at a given pH value and is usually stated in milliequivalent per 100 gram of soil (meq/100 g). In SI units, it is expressed as centimole per kilogram of soil (cmol/kg). The values presented in either meq/100 g or cmol/kg are equivalent. Usually the Cation Exchange Capacity (*CEC*) is measured at neutral pH values (pH=7). Soils differ in their Cation Exchange Capacity (*CEC*) values according to grain size distribution, type and amount of different clay minerals present. For example, approximate value of *CEC* for Sand is 2 meq/100 g, Kaolinite 3 meq/100 g, Illite 25 meq/100 g, Montmorillonite 100 meq/100 g. Besides these, Cation Exchange Capacity (*CEC*) of soil is also influenced by presence of organic matter and pH value of soil.

Cation Exchange Capacity (*CEC*) of fine grained soils can be determined by various methods but there are two standardised method given by International Soil Reference and Information Centre namely (1) Extraction with Ammonium Acetate Method and (2) Silver Thiourea Method. The various methods used for determining Cation Exchange Capacity (*CEC*) leads to inconsistent results. The most frequently used method for determining Cation Exchange Capacity (*CEC*) is the Ammonium Acetate method at neutral pH value. Also Silver Thiourea is toxic in nature.

Many properties of the fine-grained soils may be clarified by the relationship between Cation Exchange Capacity (*CEC*) and other geotechnical properties. By adding lime the existing cations attached to the surface of the soil particles can be replaced with calcium ions which leads to several improvements in the soil properties. These constructive changes are in the form of increase in the strength, reduction in plasticity, and reduction in the compressibility. The factors on which the replace ability of cations depend are valency, ion size and relative abundance of different ion type. A small ion size replaces the larger ion size. If all other factors are same the cations with high valency replaces the cations with low valency. But it is possible to replace a high valency cations with low valency cations when there is a high concentration of low valency cations in the soil solution. A typical replace ability series given by Mitchell and Soga (2005) is as follows:

$$Na^{+} < Li^{+} < K^{+} < Cs^{+} < Mg^{+2} < Ca^{+2} < Cu^{+2} < Al^{+3} < Fe^{+3}$$

It is necessary to have the knowledge of Cation Exchange Capacity (*CEC*) of the soil in many areas of geotechnical engineering such as chemical stabilization, waste containment system etc. The addition of lime to a soil provides an excess of calcium ions which leads to replacement of all other cations with divalent calcium, Ca^{+2} leading to stabilization of soil. Soils with high value of *CEC* have the potential to retain more cations in waste containment system (landfill) and thereby reducing the risk of contamination of soil, subsurface soil and ground water. Also Cation Exchange Capacity (*CEC*) is used in agricultural field as an indicator of fertility of soil.

2. LITERATURE REVIEW

2.1 Introduction

The surface properties like Cation Exchange Capacity (*CEC*) and specific surface area influence the engineering properties of fine grained soils. Cation Exchange Capacity (*CEC*) is defined as the capacity of a soil to hold a certain amount of exchangeable ions at a given pH value. It is well documented in literature that adsorption capacity of soil is closely related to Cation Exchange Capacity (*CEC*). In many areas of geotechnical engineering such as chemical stabilization, waste containment system etc. It is necessary to have the knowledge of Cation Exchange Capacity (*CEC*) of the soil. Addition of lime leads to stabilization of the soil as well as can enhance the *CEC* of soil.

Therefore, the literature review is focused extensively in two areas i.e. Cation Exchange Capacity (*CEC*) and Effect of additives on Cation Exchange Capacity (*CEC*), Compaction characteristics and Unconfined Compressive Strength.

2.2 Cation Exchange Capacity (*CEC*)

It has been suggested that Cation Exchange Capacity (*CEC*) of soil correlates significantly with engineering parameters such as specific surface area and liquid limit (Yukselen and Kaya 2006). The reactivity of the soil varies because of the differences in particle size distribution, mineralogical and organic composition (Carter et al. 1986). Grinding of clay increases the Cation Exchange Capacity (*CEC*) of clay because of the increase in surface area (Kelly et al. 1936). Cation Exchange Capacity (*CEC*) of fine grained soil is related to the amount and kind of clay mineral present.

2.2.1 Mineralogy and Cation Exchange Capacity (CEC)

The Cation Exchange Capacity (*CEC*) of a soil is dependent on the mineralogy, size, and shape of the constituent particles. Cation Exchange Capacity (*CEC*) increases with decreasing size of constituent particles as the surface area increase. Thompson et al. (1989) suggested that evaluation of the contribution made by organic matter to Cation Exchange Capacity (*CEC*) and Specific Surface Area (*SSA*) of soil materials are difficult.

Table 2.1. Cation Exchange Capacity (*CEC*) of different clay minerals (Advanced soil mechanics, B M Das) (2008)

Clay mineral	Cation Exchange Capacity (*CEC*) (meq/100 g)
Kaolinite	3
Illite	25
Montmorillonite	100
Vermiculite	150

2.2.2 Atterberg limit and Cation Exchange Capacity (*CEC*)

Atterberg limits can yield significant information about the behaviour of soils. Atterberg limits are water contents at boundaries that show characteristic engineering behaviours. The correlations so far have been developed at various plasticity level are mentioned below.

2.2.2.1 Liquid limit

Farrar and Coleman (1967) developed the linear regression equation between liquid limit and Cation Exchange Capacity (*CEC*) given by

$$CEC=0.45*LL-5 \quad (R^2=0.9) \tag{2.1}$$

Similarly, Smith et al. (1985) obtained the relation between liquid limit and Cation Exchange Capacity (*CEC*) using linear regression expressed as

$$CEC = 1.74*LL-38.3 \quad (R^2=0.72) \tag{2.2}$$

Furthermore, Yukselen and Kaya (2006) proposed the equation between liquid limit and Cation Exchange Capacity (*CEC*) using linear regression given by

$$CEC= 0.2027*LL+16.231 \quad (R^2=0.61) \tag{2.3}$$

2.2.2.2 Plastic limit

Plastic limit (*PL*) is another important index property for identifying soil behaviour. The *PL* is defined as the moisture content at which a thread of soil just crumbles when it is cautiously rolled out to a diameter of 3 mm (Holtz and Kovacs (1981)).

Smith et al. (1985) obtained the linear regression equation between *CEC* and *PL* which is expressed as

$$CEC=3.57*PL-61.3 \quad (R^2=0.56) \tag{2.4}$$

Yukselen and Kaya (2006) developed the relationship between *CEC* and *PL* using linear regression given by

$$CEC=2.3067*PL-40.3 \quad (R^2=0.46) \tag{2.5}$$

2.2.2.3 Shrinkage limit

Yukselen and Kaya (2006) obtained no significant relationship between Cation Exchange Capacity (*CEC*) and shrinkage limit as the correlation coefficient between shrinkage limit and Cation Exchange Capacity (*CEC*) was R^2=0 .2071 for the linear regression equation expressed as

$$CEC= -1.7643*SL+85.33 \quad (R^2=0.2) \tag{2.6}$$

2.2.3 Plasticity and Cation Exchange Capacity (CEC)

The difference between the *LL* and the *PL* (*PI =LL–PL*) is defines as plasticity index. Yukselen and Kaya (2006) obtained the relationship between *CEC* and *PI* using linear regression equation expressed by

$$CEC=0.1873*PI+33.13 \quad (R^2=0.3574) \tag{2.7}$$

2.2.4 Specific surface area and Cation Exchange Capacity (CEC)

Gill and Reaves (1957) developed the correlation equations for relationships between *CEC* and specific surface area as

$$CEC=0.15*SSA-1.99 \quad (R^2=0.95) \tag{2.8}$$

Farrar and Coleman (1967) suggested the relationship between *CEC* and *SSA* for British clay soils using linear regression equation as

$$CEC=0.28*SSA+2 \quad (R^2=0.90) \tag{2.9}$$

Banin and Amiel (1970) developed the correlation equations between *CEC* and *SSA* for soils in Israel as

$$CEC=0.12*SSA+3.23 \tag{2.10}$$

Churchman and Burke (1991) proposed linear regression equation between *CEC* and Specific Surface Area (*SSA*) which was obtained by Ethylene Glycol Monoethyl Ether (EGME) method expressed as

$$CEC=0.54*SSA-6.1 \quad (R^2=0.86) \tag{2.11}$$

Tanaka and Locat (1999) obtained the relationship between *CEC* and *SSA* using linear regression equation given by

$$CEC=0.14*SSA+3.6. \tag{2.12}$$

Yukselen and Kaya (2006) developed the linear regression equation between *CEC* and EGME *SSA* expressed as

$$CEC=0.1135*SSA^{1.1371} \quad (R^2=0.83) \tag{2.13}$$

Kumar and Sreedeep (2011) suggested the relationship between *CEC* and *SSA* expressed by

$$CEC=0.104*SSA+3.09 \quad (R^2=0.96) \tag{2.14}$$

2.2.5 Clay Fraction and Cation Exchange Capacity (CEC)

In general, it is expected that as the clay fraction increases, so would the *CEC* of the soil. Yukselen and Kaya (2006) proposed that there is no significant relationship between clay fraction and Cation Exchange Capacity (*CEC*) on the basis of their data. This is because *CEC* is dependent more on the type of clay mineral than on its amount.

2.2.6 Organic matter and Cation Exchange Capacity (CEC)

Caravaca et al. (1999) proposed a relationship between Total Organic Carbon (*TOC*) and Cation Exchange Capacity (*CEC*) based on linear regression expressed as

$$CEC=0.49*TOC+9.45 \quad (R^2=0.79) \tag{2.15}$$

Rashidi and Seilsepour (2008) suggested linear regression equation between Organic Carbon (OC) and Cation Exchange Capacity (*CEC*) given by

$$CEC = 8.72*OC+7.93 \quad (R^2=0.74) \tag{2.16}$$

2.2.7 Activity and Cation Exchange Capacity (CEC)

The Skempton activity, A, relates plasticity (PI) to the clay size fraction, $A = PI/CF$. Churchman and Burke (1991) and Cerato (2001) found no significant relationship between

CEC and activity of soil. Yukselen and Kaya also (2006) obtained no significant relationship between the *CEC* and activity of the soils tested (coefficient of correlation r^2=0.36).

2.2.8 Modified free swell index and Cation Exchange Capacity (CEC)

Yukselen and Kaya (2006) obtained the linear regression equation between *MFSI* and *CEC* expressed as

$$CEC = 24.629 * \log_e (MFSI) + 3.4534 \quad (R^2 = 0.66) \qquad (2.17)$$

2.2.9 Hydraulic conductivity and Cation Exchange Capacity (CEC)

Rao and Matthew (1995) suggested that hydraulic conductivity is significantly affected by the valency and size of adsorbed cations. Rao et al. found that as valency of the adsorbed cations increases hydraulic conductivity increases and hydraulic conductivity decreases for a constant valency with an increase in hydrated radius of the adsorbed cations.

2.2.10 Compressibility and Cation Exchange Capacity (CEC)

Matthew (1997) suggested that an increase in valency of the adsorbed cations leads to a decrease in compression index, and compressibility increses at a constant valency with an increase in the hydrated radii of the adsorbed cations.

2.2.11 Multiple linear regression equation for predicting Cation Exchange Capacity (CEC)

Yukselen and Kaya (2006) evaluated the contribution of several physical and chemical properties of soil to Cation Exchange Capacity (*CEC*) and obtained the following linear regression equation as follows

$$CEC = -0.33 * LL + 0.4 * SSA + 8.8 \quad (R^2 = 0.91) \qquad (2.18)$$

$$CEC = 0.1135 * SSA^{1.1371} \quad (R^2 = 0.83) \qquad (2.19)$$

$$CEC = 2.12 * OM + 0.19 * SSA + 0.38 \quad (R^2 = 0.77) \qquad (2.20)$$

where SSA is Specific Surface Area obtained by Ethylene glycol mono-ethyl ether method; *LL* is Liquid Limit; *OM* is Organic Matter; *CEC* is Cation Exchange Capacity (*CEC*).

Table 2.2. List of Equations developed so far for predicting Cation Exchange Capacity (*CEC*)

Equation	R^2 value	Author	Soil Type
$CEC=0.45*LL-5$	*0.90*	Farrar and Coleman (1967)	British clay soils.
$CEC = 1.74*LL-38.3$	*0.72*	Smith et al. (1985)	Israel
$CEC= 0.2027*LL+16.231$	*0.61*	Yukselen and Kaya (2006)	Soils in Turkey
$CEC=3.57*PL-61.3$	*0.56*	Smith et al. (1985)	Israel
$CEC=2.3067*PL-40.3$	*0.46*	Yukselen and Kaya (2006)	Soils in Turkey
$CEC= -1.7643*SL+85.33$	*0.2071*	Yukselen and Kaya (2006)	Soils in Turkey
$CEC=0.1873*PI+33.13$	*0.3574*	Yukselen and Kaya (2006)	Soils in Turkey
$CEC=0.15*SSA-1.99$	*0.95*	Gill and Reaves (1957)	South eastern US clay.
$CEC=0.28*SSA+2$	*0.90*	Farrar and Coleman (1967)	British clay soils.
$CEC=0.12*SSA+3.23$	-	Banin and Amiel (1970)	Israel soils.
$CEC=0.54* SSA-6.1$	*0.86*	Churchman and Burke (1991)	New Zealand and Fiji.
$CEC=0.14*SSA+3.6$	-	Tanaka and Locat (1999)	Osaka bay clay.
$CEC=0.1135*SSA^{1.1371}$	*0.83*	Yukselen and Kaya (2006)	Soils in Turkey.
$CEC=0.104*SSA+3.09$	*0.96*	Kumar and Sreedeep (2011)	Different proportion of swelling soil and soils in Guwahati
$CEC =0.49*TOC+9.45$	*0.79*	Caravaca et al. (1999)	Murcia, Spain
$CEC = 8.72*OC+7.93$	*0.74*	Rashidi and Seilsepour (2008)	Varamin, Iran
$CEC= 24.629*\log_e(MFSI)+3.4534$	*0.66*	Yukselen and Kaya (2006)	Soils in Turkey
$CEC =-0.33*LL+0.4* SSA+8.8$	*0.91*	Yukselen and Kaya (2006)	Soils in Turkey
$CEC = 0.1135* SSA^{1.1371}$	*0.83*	Yukselen and Kaya (2006)	Soils in Turkey
$CEC = 2.12*OM+0.19*SSA+0.38$	*0.77*	Yukselen and Kaya (2006)	Soils in Turkey

2.3 Effect of lime

Lime stabilization is one of the oldest methods that is used for improving the geotechnical properties of the soil such as decrease in plasticity and swell potential, better workability, improved strength and stiffness, and improved durability. One of the factors affecting the lime stabilization process is the amount of lime used in stabilizing the soil. The percentage of lime to be used for any modification or stabilization depends on the soil type to be stabilized. The requirement of the quantity of lime best suitable for the soil is based on an analysis of the effect that different lime percentages have on the increase in strength of the soil and the reduction of plasticity.

2.3.1 Effect of lime on Cation Exchange Capacity (CEC)

Mathew and Rao (1997) built a test tank of plan dimension 1000 mm × 1000 mm and depth 750 mm and installed lime columns at predetermined positions as shown in figure 2.1. The pH, lime content and Cation Exchange Capacity (*CEC*) was measured with varying time at sample locations. The Lime content, pH value, and Cation Exchange Capacity (*CEC*) values increased with time.

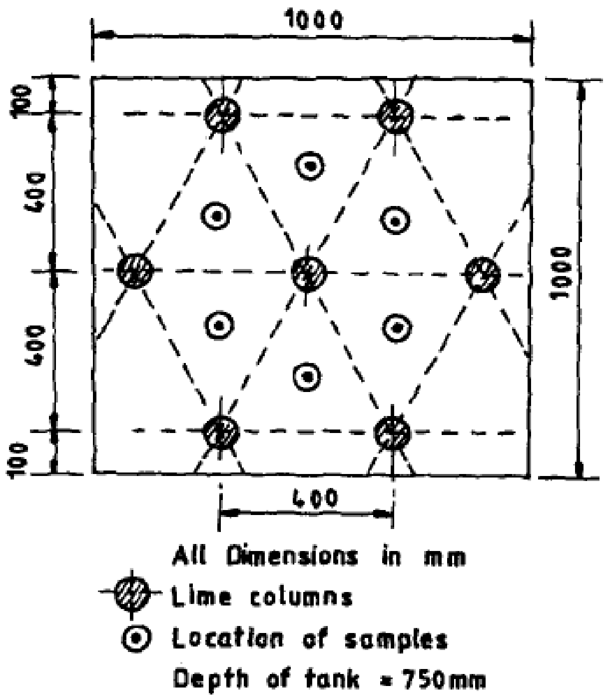

Figure 2.1. Plan view of test tank Used by Mathew and Rao (1997)

Akbulut and Arasan (2010) studied the effect of additives such as lime, cement, fly ash, and silica fume in expansive soils on Cation Exchange Capacity (*CEC*), pH and Zeta potential. The Cation Exchange Capacity (*CEC*) and Zeta potential decreased with increase in lime content while pH increased with increase in lime content.

2.3.2 Effect of lime on Compaction characteristics and Unconfined Compressive strength

Zhang and Xing (2002) studied the stabilization of expansive soil by lime and fly ash. The Optimum Moisture Content increased and the Maximum Dry Density decreased with increase in percentage of lime.

Kumar et al. (2007) studied the effect of fly ash, lime, and polyester fibers on compaction and strength properties of expansive soil. With the increase in Lime content there is an increase in optimum Moisture content and decrease in maximum dry density. The Curing time did not increased the strength up to 4% of lime content. With the increase in the percentage of lime, strength increases and attains a certain maximum value and after that it starts decreasing.

Sakr et al. (2008) studied the geotechnical properties of soft clay organic soil stabilized with varying lime percentages of 1, 3, 5 and 7 percent. The unconfined compressive strength of 7 percentage lime increased nearly seven times for 60 day curing period.

Amu et al. (2011) tested the lime stabilization requirement and suitability of lime for three lateritic soil samples. These 3 soil samples were mixed with 2, 4, 6, 8, and 10 percent of lime and tested for compaction, CBR test, unconfined compression and undrained triaxial test. The CBR value, unconfined compressive strength and shear strength of the composite soil samples was improved to maximum value at 8 percent, 6 percent and 6 percent for the 3 soil samples.

Davoudi and Kabir (2011) tested a low plasticity soil for interaction with lime and sodium chloride. They concluded that unconfined compressive strength of soil increases with increase in lime content and curing time. However, after comparing the rate of increase in unconfined compressive strength, they concluded the optimum lime content as 6 percent.

Siddique and Hossain (2011) studied the influence of lime stabilization on engineering properties of expansive soil. The soil was stabilised with lime contents of 3%, 6%, 9%, 12%

and 15%. The Optimum moisture content increased and maximum dry density decreased with increase in lime content. Unconfined compressive strength of the sample increased with increase in lime content. There was large increase in unconfined compressive strength with increase in curing period of upto 16 weeks.

Dash and Hussain (2012) studied the influence of lime on a silica rich non expansive soil and expansive soil. They concluded that beyond certain limits, the addition of lime reduces the improvement in strength predominantly in silica rich soil because of the formation of excess silica gel which is a highly porous structure.

Kaur and Singh (2012) found that the Optimum Moisture Content increased and the Maximum Dry Density decreased with the addition of lime. The soil gains compressive strength on addition of lime, but it continues only upto a certain percentage of lime and then it starts decreasing with the increase in lime content.

Muhmed and Wanatowski (2013) obtained the initial consumption of lime by the pH test given by Eades and Grim as 5 percent. The unconfined compressive strength was conducted on the composite soil sample at Optimum Moisture Content (*OMC*), wet side of *OMC* and dry side of *OMC*. They found that the maximum unconfined compressive strength developed at the Optimum Moisture Content (*OMC*).

Bairwa et al. (2013) studied the effect of lime and fly ash on geotechnical properties of Black cotton soil. At first, the Optimum Moisture content decreased and the Maximum Dry Density increased with the addition of 3% lime. Then a further increase in lime content resulted n increase of the Optimum Moisture content and the decrease of Maximum Dry Density.

2.4 Effect of Fly ash

2.4.1 Effect of fly ash on Cation Exchange Capacity (CEC)

Nalbantoglu (2004) observed the effect of fly ash for stabilizing expansive soil. He studied the effect of Fly ash on plasticity characteristics, swelling and Cation Exchange Capacity (*CEC*) of two soils. The Cation Exchange Capacity (*CEC*) of both the soils decreased with increase in fly ash content.

Akbulut and Arasan (2010) studied the variation of Electro-kinetic properties such as Cation Exchange Capacity (*CEC*), pH and Zeta potential in expansive soils treated with additives such as lime, cement, fly ash, and silica fume. With increase in fly ash content, the Cation Exchange Capacity (*CEC*) values decreased.

2.4.2 Effect of Fly ash on Compaction characteristics and Unconfined Compressive strength

Zhang and Xing (2002) studied the stabilization of expansive soil by lime and fly ash. The increase in fly ash content leads to decrease in Maximum Dry Density and increase in Optimum Moisture Content.

Kolias et al. (2005) stabilised three soils predominantly clayey with fly ash and cement. The soil was tested with 5, 10 and 20 percent fly ash. The maximum dry density decreased and Optimum moisture content increased with increase in fly ash. For all the soils, with increase in fly ash content the Unconfined Compressive Strength increased.

Sezer et al. (2006) studied the utilization of a fly ash for improvement in clay properties. They observed the effect of fly ash on compaction characteristics, unconfined compressive strength and shear strength parameters of soil. The maximum dry density decreased and the optimum moisture content increased with increase in fly ash content. The unconfined compressive strength of the soil increased with the addition of fly ash. There was no appreciable increase in unconfined compressive strength after 28 days. At later stages a considerable increase in cohesion intercept was observed in samples containing high percent of fly ash.

Kumar et al. (2007) studied the effect of fly ash, lime, and polyester fibers on compaction and strength properties of expansive soil. With the increase in fly ash content there is an increase in optimum Moisture content and decrease in maximum dry density.

Bairwa et al. (2013) studied the influence of lime and fly ash on engineering properties of Black cotton soil. With the increase in fly ash content, the Optimum Moisture Content increased and the Maximum Dry Density decreased.

2.5 Scope of the present study

Based on the review of the existing literature on the Cation Exchange Capacity (*CEC*) of soils, it appears that various relationship for predicting Cation Exchange Capacity (*CEC*) of soil from geotechnical properties with varying degree of accuracy have been proposed.

A large number of studies have been done on the geotechnical properties of the soil but the studies on electro-kinetic properties of the soil such as Cation Exchange Capacity (*CEC*) are limited in literature.

As the knowledge of the Cation Exchange Capacity (*CEC*) is essential in waste containment system, the objective of the thesis is to study the effect of adding additives like lime and fly ash on the Cation Exchange Capacity (*CEC*) of treated soil for better holding of pollutant cations in waste containment system.

The objective of the present study is as follows

- Effect of lime and fly ash on Cation Exchange Capacity (*CEC*) of composite soil sample.
- To obtain the optimum lime content for maximum Unconfined Compressive Strength (*UCS*) of treated soil sample with varying lime content for a certain curing period.
- To obtain the optimum fly ash content for maximum Unconfined Compressive Strength (*UCS*) of treated soil sample with varying fly ash content for a certain curing period.

3. MATERIAL CHACTERISATION AND METHODOLOGY

3.1 Introduction

This chapter presents the investigation methods to be used to determine geotechnical characteristics of the soil samples. The laboratory testing program consists of geotechnical tests such as Atterberg limit test, grain size analysis, specific gravity test, compaction test, unconfined compressive strength and direct shear test. The other test to be performed are Cation Exchange Capacity (*CEC*) test and pH test.

3.2 Material Characteristics and Methodology

Soil sample was collected from two sites in Odisha. One from the periphery of ash pond area of Sesa Sterlite limited, Jharsuguda, Odisha and the other soil was collected from NTPC Darlipalli, Suratgarh, Odisha. Both the soil sample was collected from 2 m below the ground level. Fly ash was collected from NSPCL Rourkela. Laboratory lime used for experimentation was taken from Fisher scientific.

3.2.1 Specific Gravity

The specific gravity of both the soil sample and fly ash was determined as per IS: 2720-Part 3 (1980) and the results are presented in Table 3.1.

Table 3.1. Specific gravity of soils and fly ash

Sample	Values
Sesa Sterlite soil sample (Sandy Clay)	2.62
NTPC Darlipalli soil sample (Low Plastic Clay)	2.66
Fly ash	2.30

3.2.2 Particle size distribution

Grain size distribution of soil samples was determined by sieve analysis and hydrometer analysis as per IS: 2720- part 4 (1985). The particle size distribution curve for the soil samples and fly ash are presented in Figure 3.1.

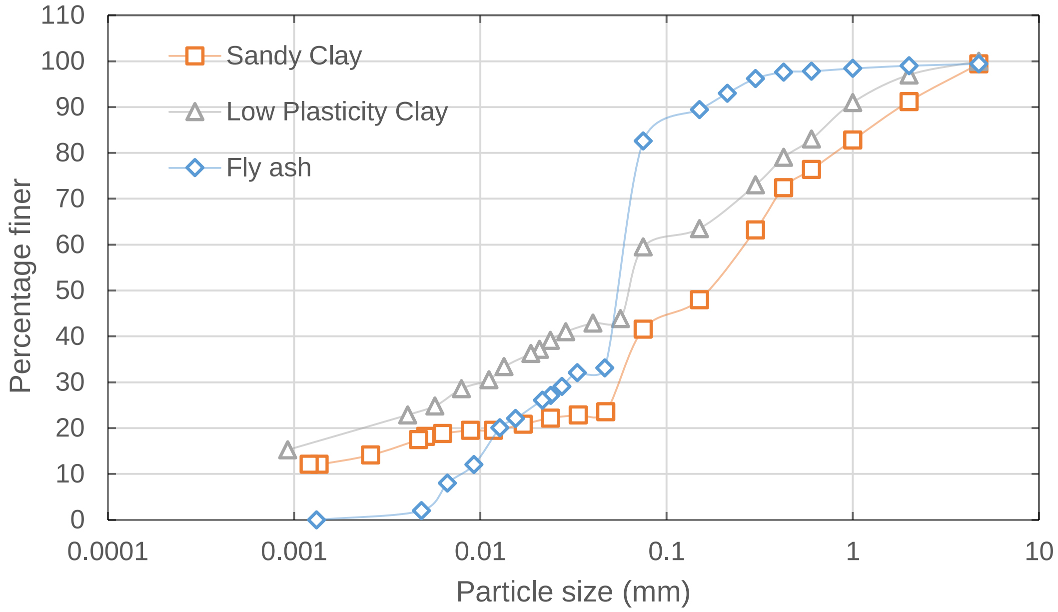

Figure 3.1. Grain Size Distribution Curve

The coefficient of uniformity i.e. $C_u = D_{60}/D_{10}$ and coefficient of curvature i.e. $Cc = (D_{30})^2/(D_{10} * D_{60})$ for the soil samples cannot be calculated as value of D_{10} is not known while the values of Cu and Cc for fly ash calculated from grain size distribution curve are 9.44 and 0.52 respectively.

Table 3.2. Grain size distribution curve parameters of soils and fly ash

Parameters	Sesa Sterlite soil sample (Sandy Clay)	NTPC Darlipalli soil sample (Low Plastic clay)	Fly ash
Coefficient of uniformity	-	-	9.44
Coefficient of curvature	-	-	0.52

3.2.3 Atterberg limit test

Shrinkage limit of soil samples was determined as per IS 2720-Part 6 (1972) and is presented in the Table 3.3. Plastic limit and liquid limit were determined as per IS 2720-Part 5(1985) and the results are presented in the Table 3.3.

Table 3.3. Atterberg limits

Limits And Indices	Sesa Sterlite soil sample (Sandy Clay)	NTPC Darlipalli soil sample (Low Plastic clay)
Shrinkage limit (%)	13.72	5.82
Plastic limit (%)	16	24
Liquid limit (%)	24	33
Plasticity index	8	9

As per Unified Soil Classification System (USCS), the soil sample from Sesa Sterlite is Sandy Clay (*SC*) and the soil sample from NTPC Darlipalli is Low Plasticity Clay (*CL*).

3.2.4 Light Compaction test

Light Compaction test was done on the soil samples and fly ash as per IS 2720-part 7 (1980). The Optimum Moisture content (*OMC*) and Maximum Dry Density (*MDD*) of the soil samples and Fly ash are given in Table 3.4.

Table 3.4. Compaction Properties of soils and Fly ash

Compaction properties	Sandy Clay	Low Plastic clay	Fly Ash
Optimum Moisture Content (OMC) (%)	13.7	16.5	35
Maximum Dry Density (MDD) (kN/m^3)	18.4	17.71	11.54

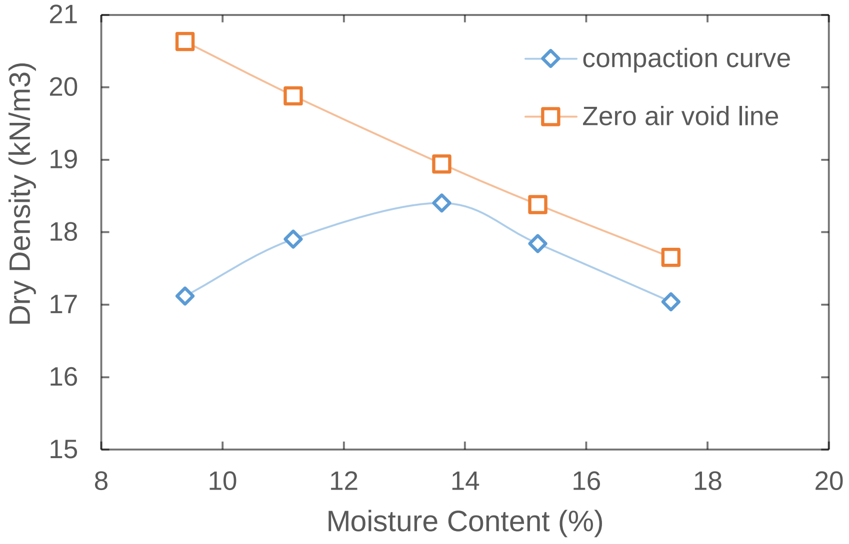

Figure 3.2. Light Compaction curve for Sandy Clay (*SC*)

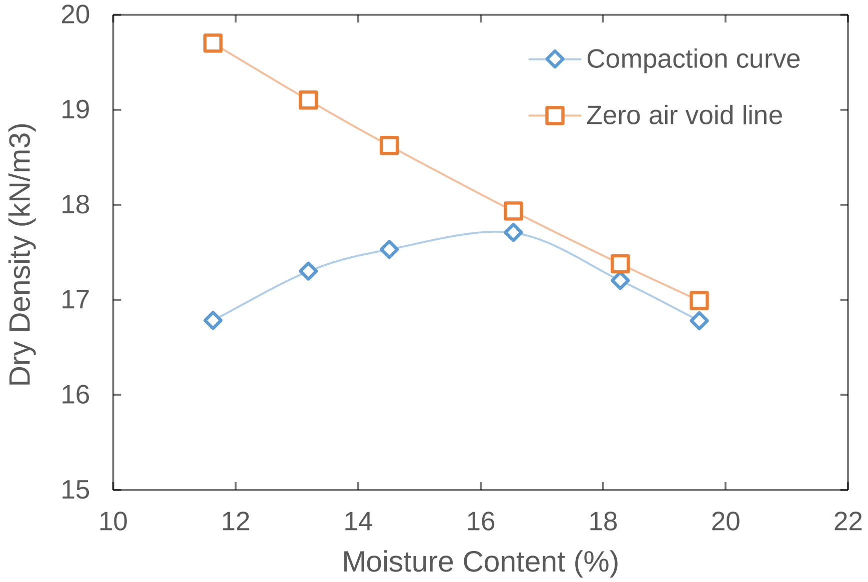

Figure 3.3. Light Compaction curve for Low Plasticity Clay (*CL*)

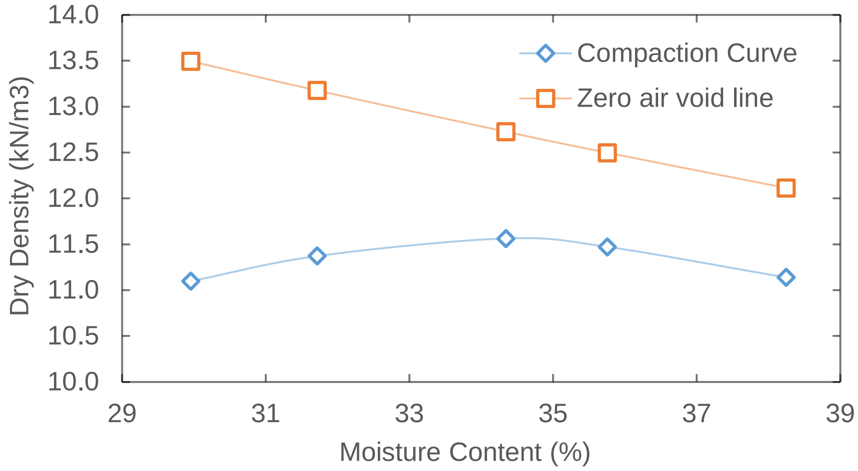

Figure 3.4. Light Compaction curve for Fly ash

3.2.5 Unconfined compressive strength

The unconfined compressive strength test was done as per IS 2720-Part 10 (1991) on the soil samples and the unconfined compressive strength of the sandy clay and low plasticity clay are is 157.36 kN/m^2 and 178.34 kN/m^2.

3.2.6 Direct Shear Test

The direct shear test was done in accordance with IS 2720-Part 13 (1986). The undrained cohesion value and angle of shear resistance for the soil samples and fly ash are presented in Table 3.5.

Table 3.5. Shear Strength parameters of soils and Fly ash

Shear Strength parameters	Sandy Clay	Low Plastic clay	Fly Ash
Cohesion (*C*) in (kPa)	24.14	43.16	0.3
Angle of shear resistance (º)	23.47	7.91	39.29

3.2.7 pH test

The pH test performed on the soil samples as per IS: 2720 (Part 26) (1987) showed the pH value for sandy clay and low plasticity clay as 7.4 and 7.3 respectively.

3.2.8 *XRD analysis*

The mineralogical analysis of the materials has been done by XRD analysis using X-ray diffraction-meter which is based on the principle that beams of X-rays diffracted from crystals are characteristics for each clay mineral group. The XRD analysis was done by Xpert high score software package and the minerals present in the soil samples and fly ash are as shown in Figures 3.5 to 3.7.

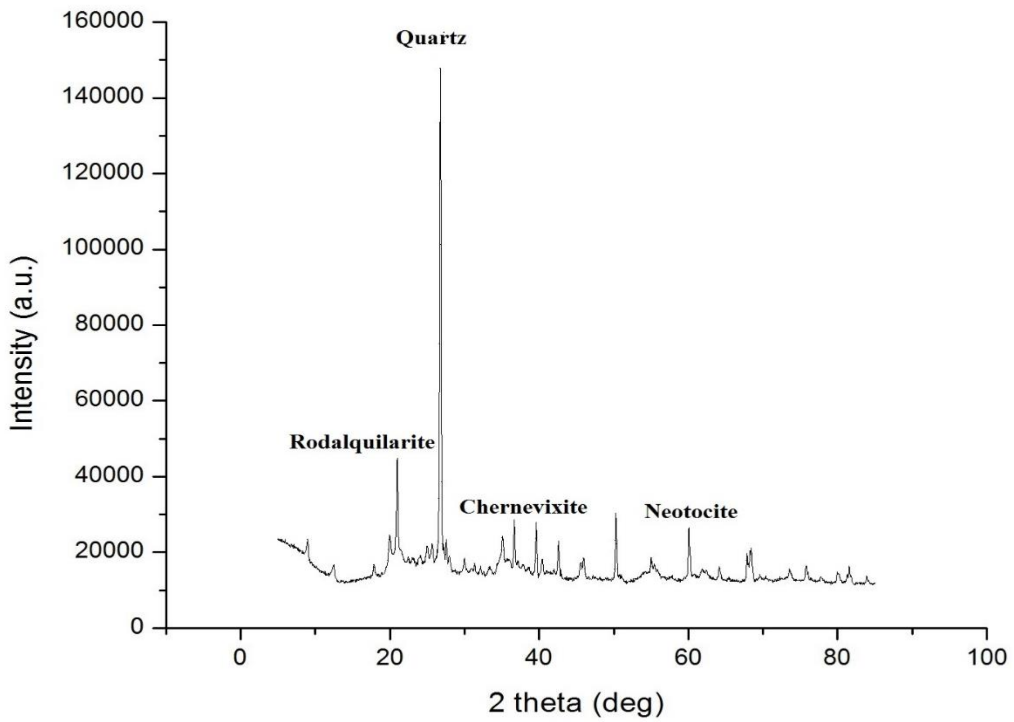

Figure 3.5. XRD Analysis of Sandy Clay

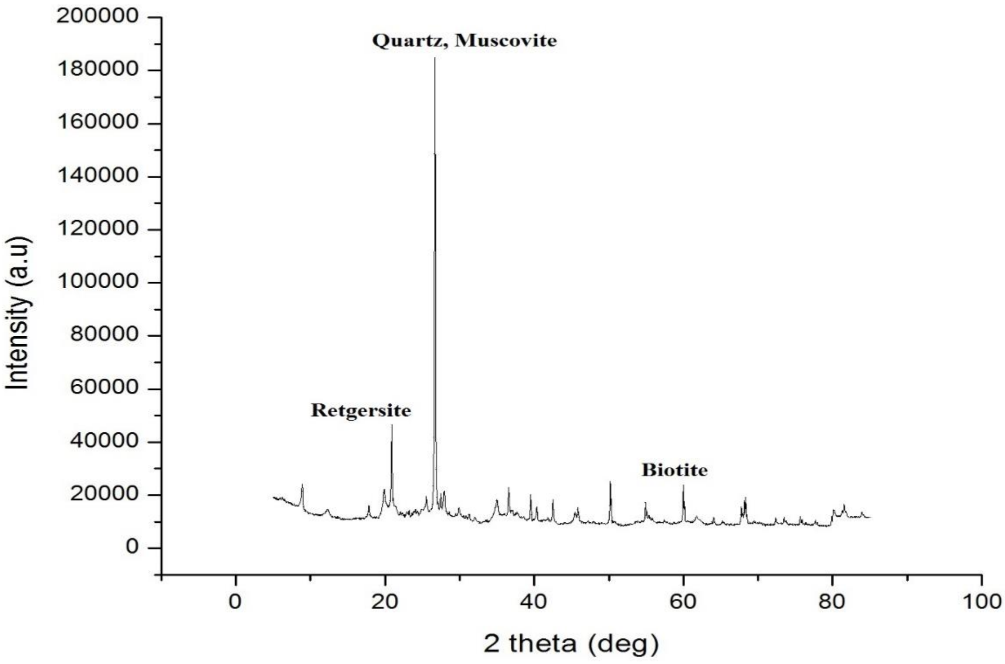

Figure 3.6. XRD Analysis of Low plasticity clay

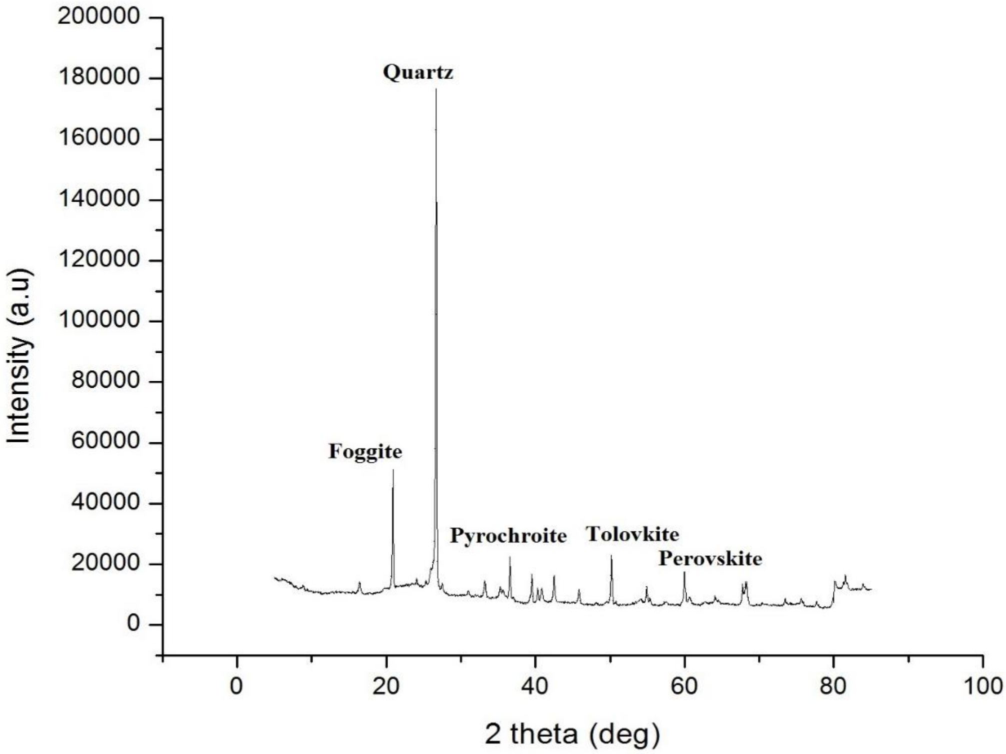

Figure 3.7. XRD Analysis of Fly ash

3.3 Cation Exchange Capacity (*CEC*)

There are two standardised method given by International Soil Reference and Information Centre namely 1) Extraction with ammonium acetate method. 2) Silver thiourea method. The Ammonium acetate method at neutral pH value is the most commonly used method for determining Cation exchange capacity (*CEC*). The ASTM D7503 – 10 method was used to determine Cation exchange capacity (*CEC*) of soil sample.

The Cation Exchange Capacity (*CEC*) of the soil sample and soil mixtures was found as per ASTM D7503 – 10 method.

Procedure:

1. 2.5 to 10 gm of soil in a 100-ml centrifuge tube was taken and 40 ml of 1 M ammonium acetate of pH 7 was added.
2. The centrifuge tube was shaken for 5 min and kept overnight.
3. Next morning it was again shaken for 15 minutes.
4. The sample was then transferred through Buchner funnel with filter paper into the vacuum flask.
5. The excess soil from centrifuge tube was rinsed.
6. The soil was washed 4 more times with 30 ml of ammonium acetate solution and the solution from vacuum flask was discarded.
7. Then the soil sample was washed 3 times with 40 ml isopropanol and the solution was discarded.
8. After that the soil was washed with potassium chloride solution 4 times with 50 ml each.
9. The solution was poured from vacuum flask into volumetric flask and extra potassium chloride solution was used to fill upto the line mark in volumetric flask (250ml).
10. 60 ml of the solution was taken to find nitrogen concentration by spectrophotometer.

The Nitrogen concentration was determined as per modified Parsons et al. (1984) by using the spectrophotometric method.

Figure 3.8. Photographic image of Spectrophotometer

Standard solution was prepared using ammonium chloride of 0.2, 0.4, 0.6, 0.8, and 0.10 ppm concentration. 5 ml of blank or standard or sample was mixed with 0.2 ml phenol and swirled. After that in sequence 0.2 ml of sodium nitroprusside and 0.5 ml of oxidizing solution was added. Then it was swirled and allowed to stand for 1 hour. The colour was stable for 24 hours. The absorbance of the solution was determined at 640 nanometre. From the blank and standard solution, the calibration curve for nitrogen determination was found. Then from the absorbance of the sample, nitrogen content of the sample can be determined.

The concentration of nitrogen was determined through the graph obtained by the absorbance of the standard solution of known concentration. The graph obtained is given in the Figure 3.9.

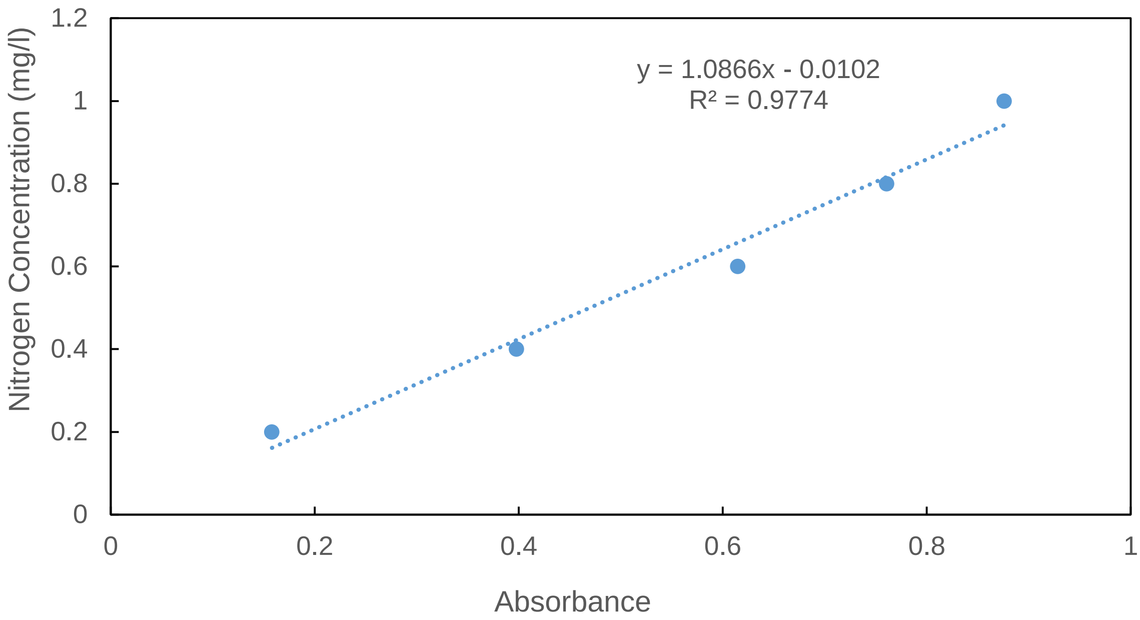

Figure 3.9. Calibration curve for nitrogen concentration

The *CEC* of the sample is calculated after knowing the nitrogen concentration by the equation

$$CEC\left(\frac{cmol}{kg}\right) = \frac{N \times 1 \times 0.25}{140 \times mass\ of\ soil\ taken} \times 1000$$

where N = nitrogen concentration in mg/L.

The Cation Exchange Capacity (*CEC*) of sandy clay and low plasticity clay are 20.16 cmol/kg and 43.43 cmol/kg.

4. RESULTS AND DISCUSSION

4.1 Introduction

A large number of studies have been done on the geotechnical properties of the soil but the studies on electro kinetic properties of the soil such as Cation Exchange Capacity (*CEC*) are limited in literature. In this Chapter, a series of experiments have been done to study the effect of the additives such as lime and fly ash on the electro kinetic properties like Cation Exchange Capacity (*CEC*) and geotechnical properties such as Compaction Characteristics and Unconfined compressive strength.

4.2 Cation Exchange Capacity (*CEC*)

4.2.1 Effect of Lime

The Cation Exchange Capacity (*CEC*) values decreased with the increase in lime content for both the soil samples as can be seen in Figure 4.1. The decrease in Cation Exchange Capacity (*CEC*) obtained are similar to that obtained by Akbulut and Arasan (2010).

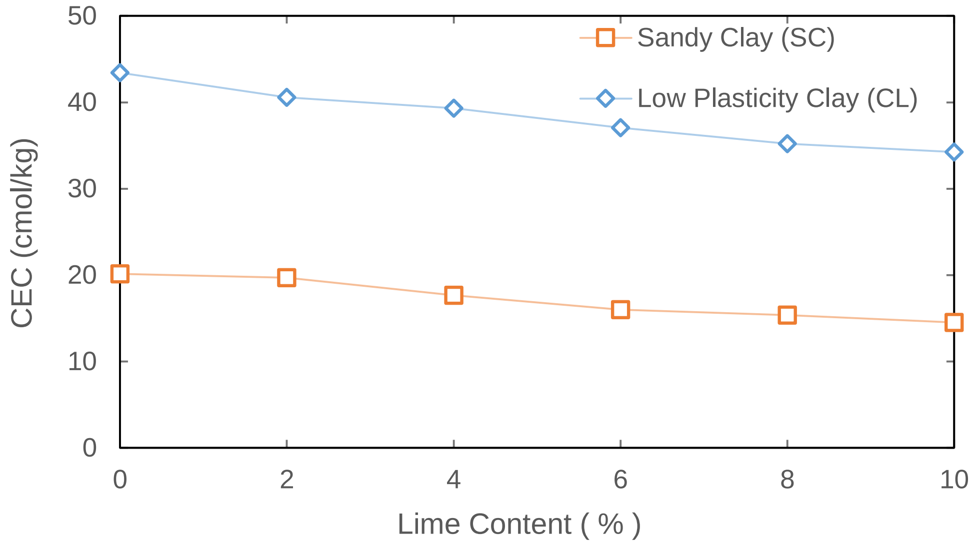

Figure 4.1. Variation in Cation Exchange Capacity (*CEC*) with lime content

Table 4.1. Effect of Lime on Cation Exchange Capacity (*CEC*)

Sample	Cation Exchange Capacity (*CEC*) (cmol/kg)	
	Sandy Clay (*SC*)	Low Plasticity Clay (*CL*)
Soil + 0% lime	20.16	43.44
Soil + 2% lime	19.70	40.56
Soil + 4% lime	17.68	39.32
Soil + 6% lime	16.00	37.06
Soil + 8% lime	15.38	35.20
Soil + 10% lime	14.53	34.24

The decrease in *CEC* values can be explained by the mineralogical changes occuring in the treated soils. The decrease in *CEC* can also be explained due to the formation of coarser particles with lime treatment which reduces the specific surface area.

4.2.2 Effect of Fly ash

As can be seen from Figure 4.2, with the increase of fly ash content in soil, the Cation Exchange Capacity (*CEC*) values decreased for both sandy clay (*SC*) and Low Plasticity clay (*CL*). It was observed that increase in fly ash content decreases Cation Exchange Capacity (*CEC*) values more rapidly when compared with increase in lime content. Similarly Akbulut and Arasan (2010) reported that fly ash is more effective in decreasing the Cation Exchange Capacity (*CEC*) values. Also, Nalbantoglu (2004) reported decrease in Cation Exchange Capacity (*CEC*) values with increase in fly ash content.

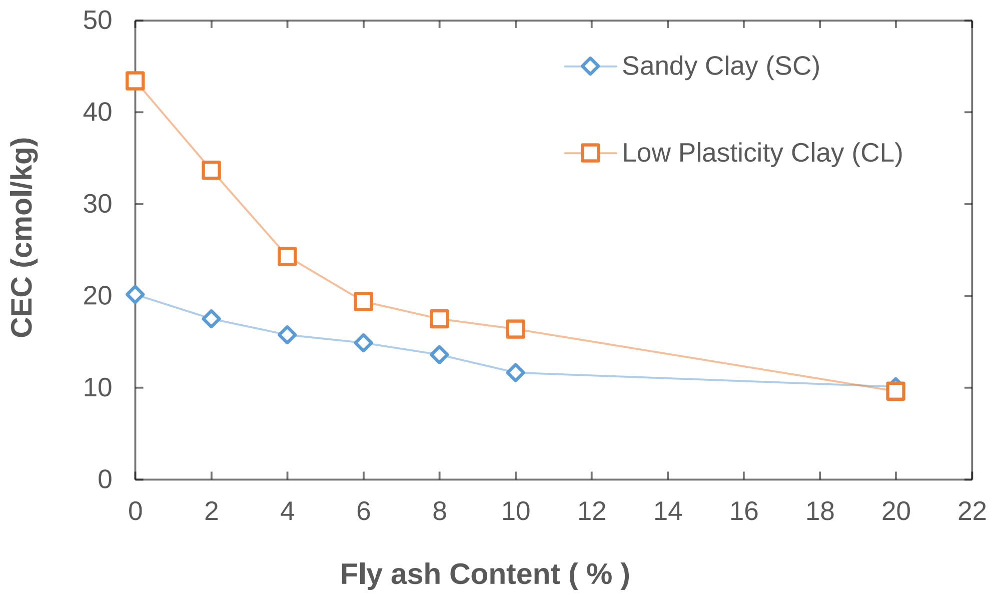

Figure 4.2.Variation in Cation Exchange Capacity (*CEC*) with Fly ash content

Table 4.2. Effect of Fly ash on Cation Exchange Capacity (*CEC*)

Sample	Cation Exchange Capacity (*CEC*) (cmol/kg)	
	Sandy Clay (*SC*)	Low Plasticity Clay (*CL*)
Soil + 0% Fly ash	20.16	43.44
Soil + 2% Fly ash	17.52	33.69
Soil + 4% Fly ash	15.77	24.32
Soil + 6% Fly ash	14.91	19.39
Soil + 8% Fly ash	13.59	17.52
Soil + 10% Fly ash	11.65	16.39
Soil + 20% Fly ash	10.13	9.63

The rapid decrease in *CEC* values with addition of fly ash content as compared to addition of lime content may be because of the higher value of pH of lime. The higher pH of lime somewhat compensates the decrease in *CEC* as with increase in pH the *CEC* value increases.

4.3 Compaction Characteristics

4.3.1 Effect of lime

The addition of lime in sandy clay and low plasticity clay results in decrease in maximum dry density and increase in optimum moisture content as can be seen from the compaction curve shown in Figures 4.3 and 4.4. Most of the researchers reported that with increase in lime content the maximum dry density decreases and optimum moisture content increases.

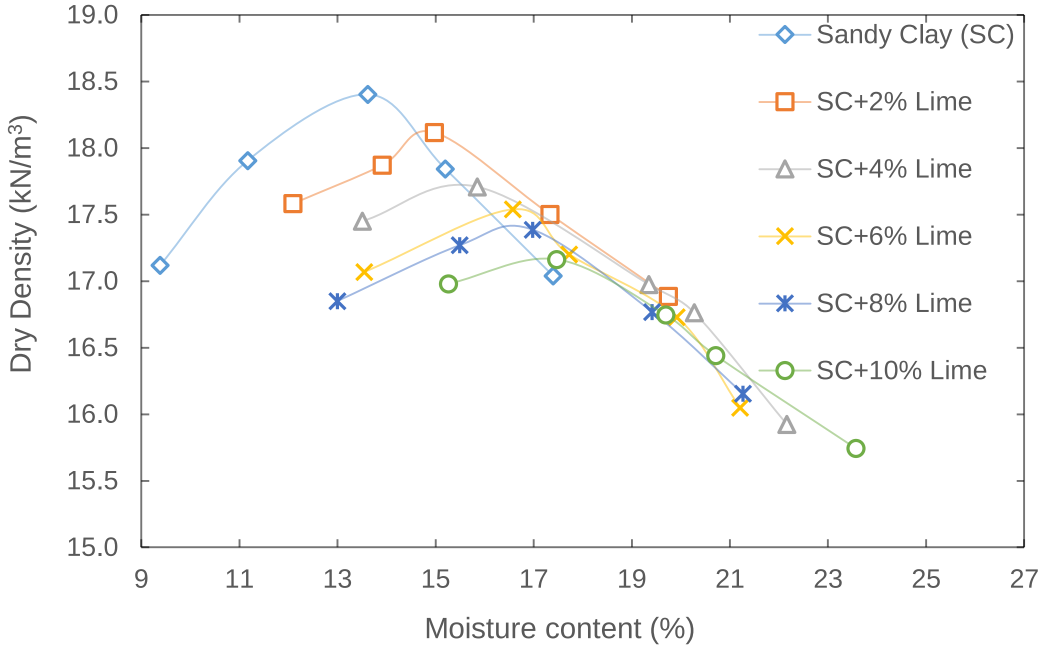

Figure 4.3. Light Compaction curve for sandy clay (*SC*) with varying percentage of lime

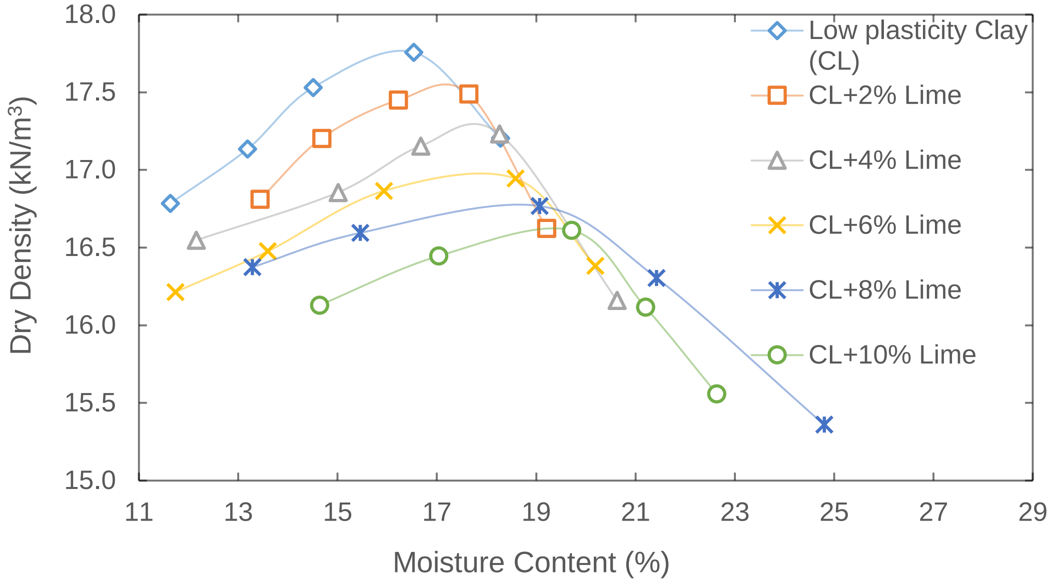

Figure 4.4. Light Compaction Curve for low plasticity clay (*CL*) with varying percentage of lime.

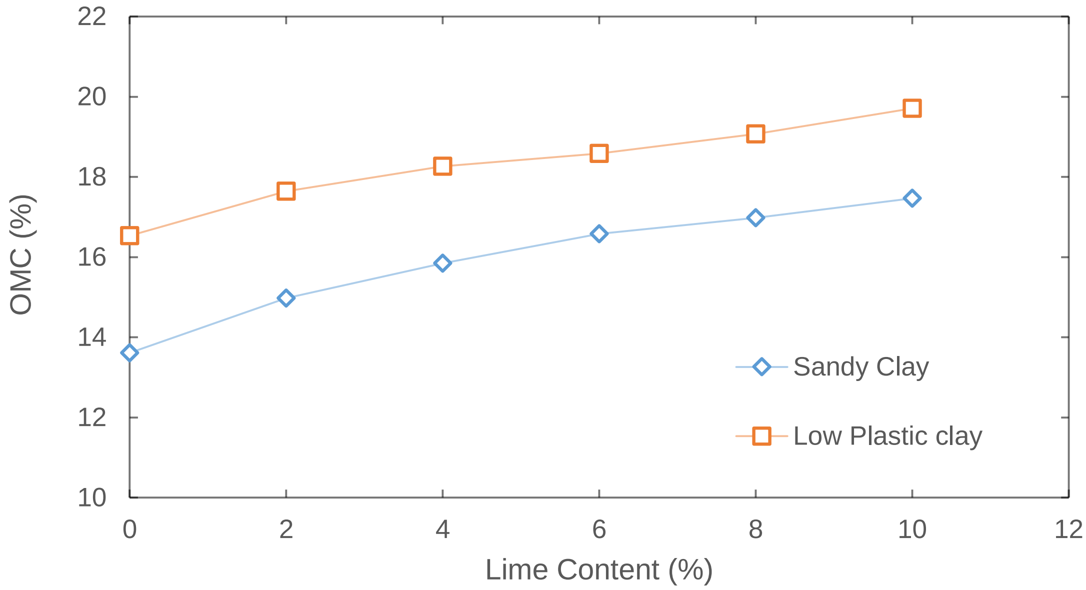

Figure 4.5. Variation of *OMC* with Lime Content

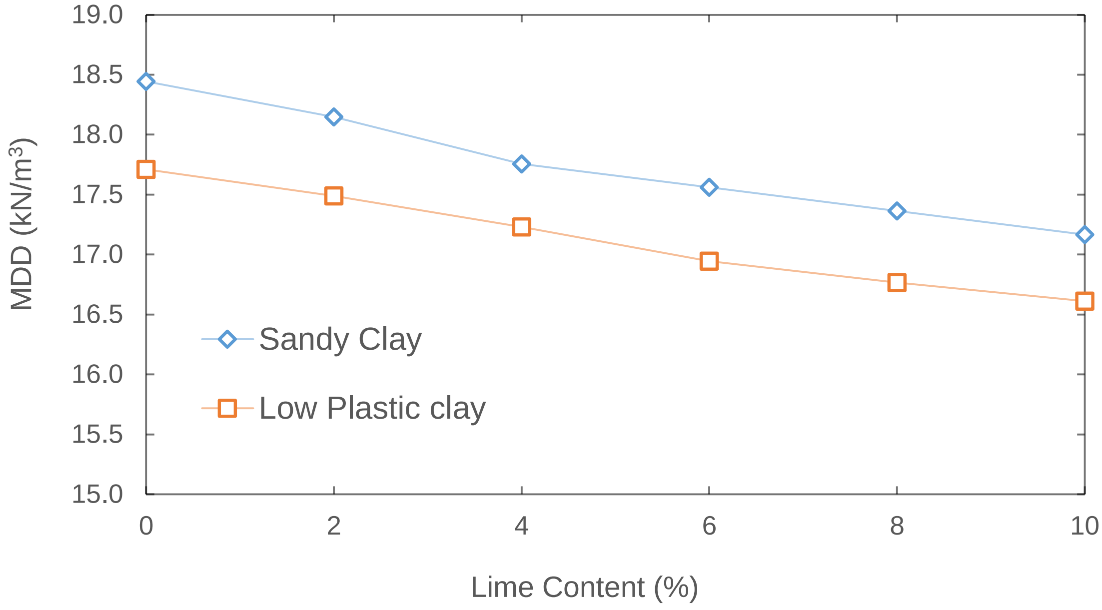

Figure 4.6. Variation of *MDD* with Lime Content

Table 4.3. Variation of *OMC* and *MDD* with varying lime content

Sample	Sand Clay (*SC*)		Low Plasticity Clay (*CL*)	
	OMC (%)	*MDD* (kN/m^3)	*OMC* (%)	*MDD* (kN/m^3)
Soil + 0% Lime	13.61	18.40	16.53	17.71
Soil + 2% Lime	14.98	18.12	17.64	17.49
Soil + 4% Lime	15.85	17.71	18.26	17.23
Soil + 6% Lime	16.58	17.54	18.58	16.94
Soil + 8% Lime	16.98	17.39	19.07	16.77
Soil + 10% Lime	17.47	17.16	19.71	16.61

With the addition of lime, the clay particles get flocculated and agglomerated to have larger void ratio which leads to decrease in maximum dry density. The water retained in these void spaces and the water required for pozzolonic reaction leads to an increase in optimum moisture content.

4.3.2 Effect of fly ash

The increase in fly ash content leads to the decrease in maximum dry density and increase in optimum moisture content for both sandy clay and low plasticity clay as can be seen from the compaction curve shown in Figures 4.7 and 4.8. Similarly, Most of the researchers reported decrease in maximum dry density and increase in optimum moisture content with the increase in fly ash content.

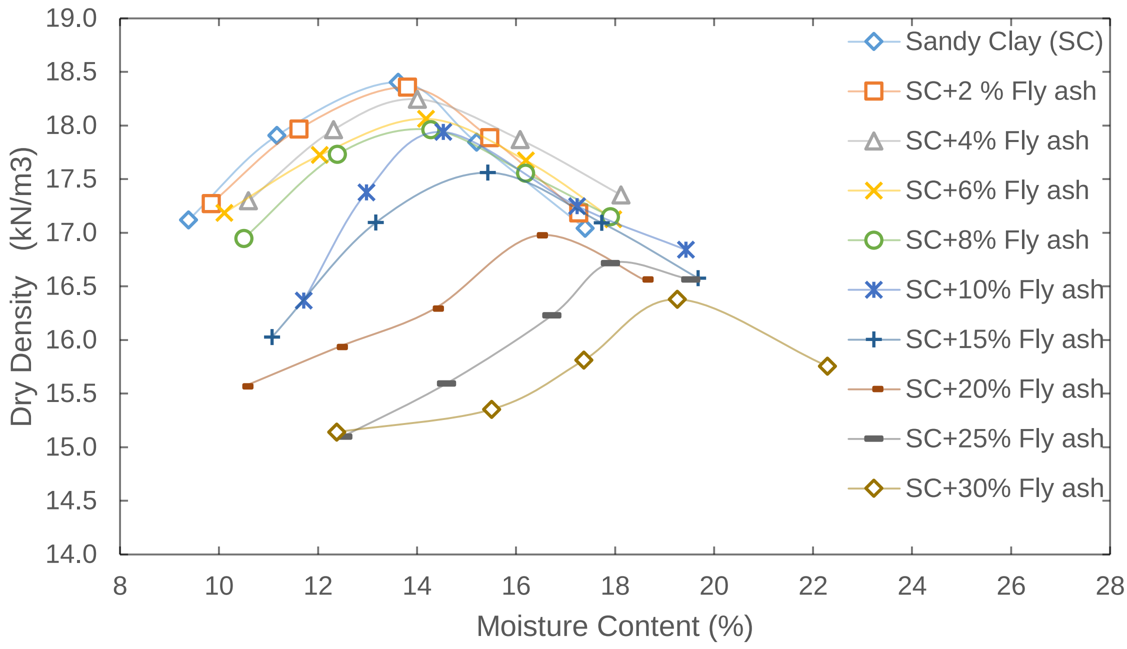

Figure 4.7. Light Compaction curve for sandy clay (*SC*) with varying percentage of Fly ash

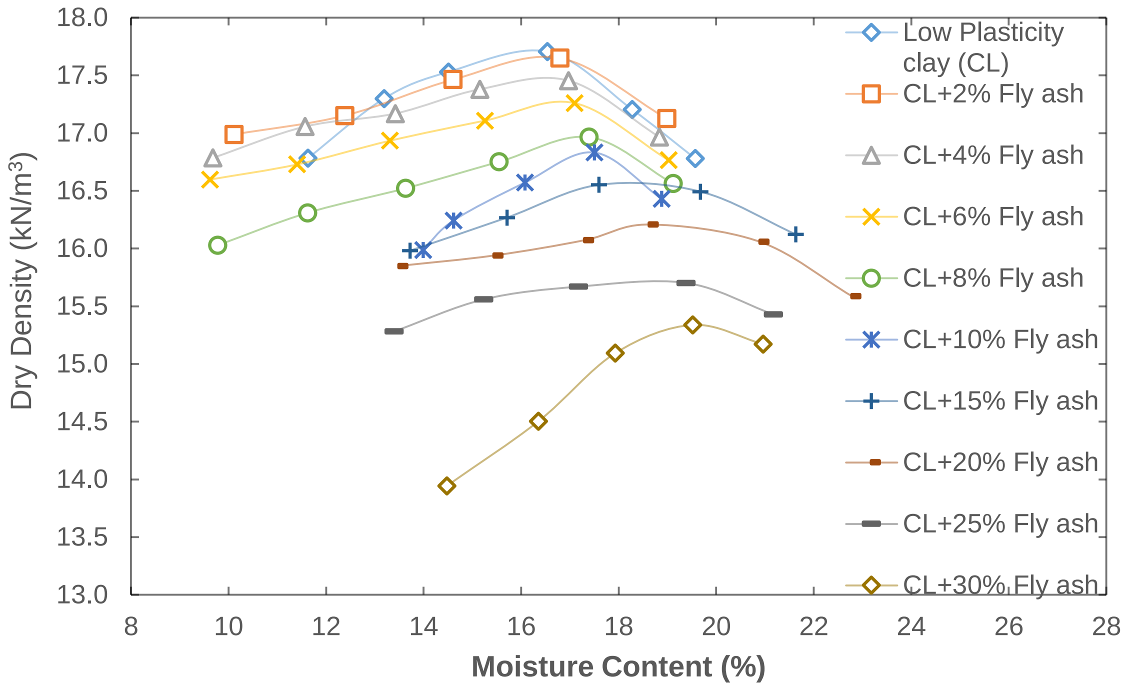

Figure 4.8. Light Compaction Curve for low plasticity clay (*CL*) with varying percentage of Fly ash.

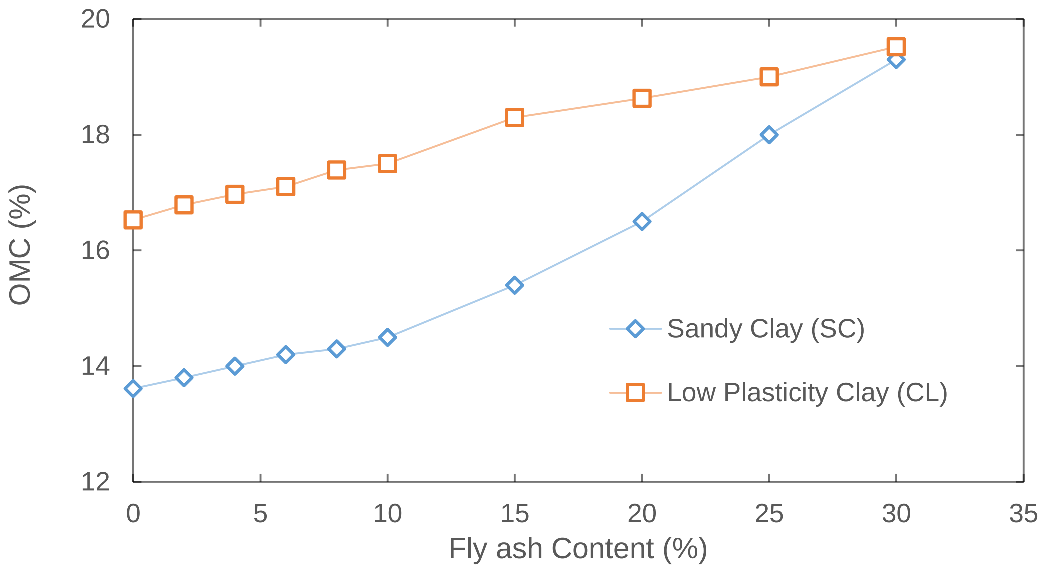

Figure 4.9. Variation of *OMC* with Fly ash Content

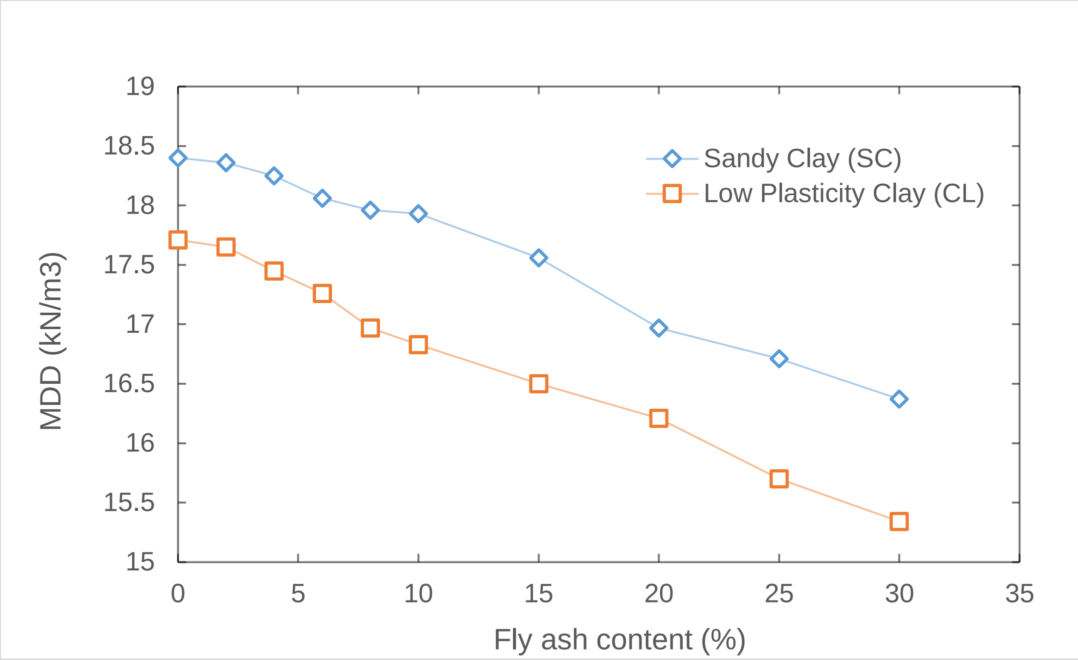

Figure 4.10. Variation of *MDD* with Fly ash Content

Table 4.4. Variation of OMC and MDD with varying Fly ash content

Sample	Sand Clay (*SC*)		Low Plasticity Clay (*CL*)	
	OMC (%)	*MDD* (kN/m^3)	*OMC* (%)	*MDD* (kN/m^3)
Soil + 0% Fly ash	13.61	18.40	16.53	17.71
Soil + 2% Fly ash	13.8	18.36	16.79	17.65
Soil + 4% Fly ash	14	18.25	16.97	17.45
Soil + 6% Fly ash	14.2	18.06	17.1	17.26
Soil + 8% Fly ash	14.3	17.96	17.39	16.97
Soil + 10% Fly ash	14.5	17.93	17.5	16.83
Soil + 15% Fly ash	15.4	17.56	18.3	16.5
Soil + 20% Fly ash	16.5	16.97	18.63	16.21
Soil + 25% Fly ash	18	16.71	19	15.7
Soil + 30% Fly ash	19.3	16.37	19.52	15.34

With the increase in fly ash content, the maximum dry density decreased due to the lower specific gravity of fly ash as compared to specific gravity of soils. Also the optimum moisture content increases less as compared with same lime content because of less pozzolonic reaction and less void ratio.

4.4 Unconfined Compressive strength

4.4.1 Effect of lime

The unconfined compressive strength of soil increases significantly with increase in lime content upto a certain percentage after which there is a decrease in unconfined compressive strength. The unconfined compressive strength of sandy clay (SC) and low plasticity clay (CL) increased with varying lime content for different curing periods as can be seen in Figures 4.11 and 4.12.

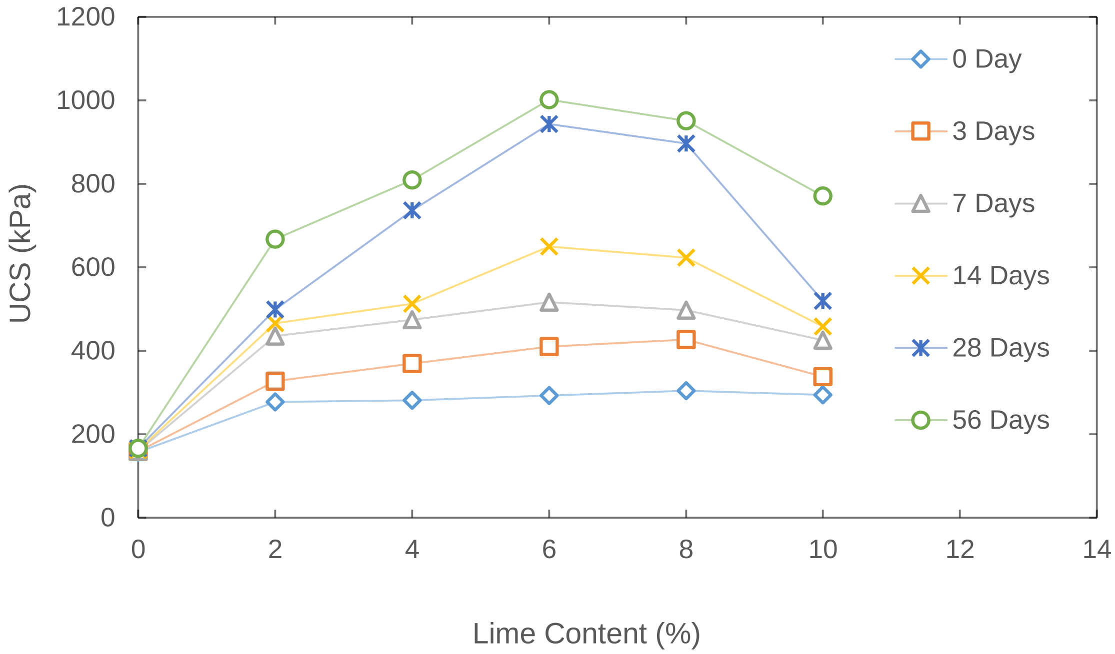

Figure 4.11. Variation in *UCS* for Sandy Clay (*SC*) stabilized with lime at different curing periods

Table 4.5. Unconfined Compressive Strength (kPa) of Lime stabilized Sandy clay (*SC*) with different curing periods

Sample	Curing Period (days)					
	0	3	7	14	28	56
SC + 0% lime	156.96	158.92	159.90	161.87	166.57	166.13
SC + 2% lime	277.62	327.65	435.56	465.97	499.32	668.06
SC + 4% lime	281.54	369.83	474.80	513.06	736.73	809.32
SC + 6% lime	293.31	410.05	516.98	650.40	943.72	1001.60
SC + 8% lime	304.11	426.73	497.36	622.93	896.63	951.57
SC + 10% lime	294.30	338.44	425.75	458.12	519.93	771.06

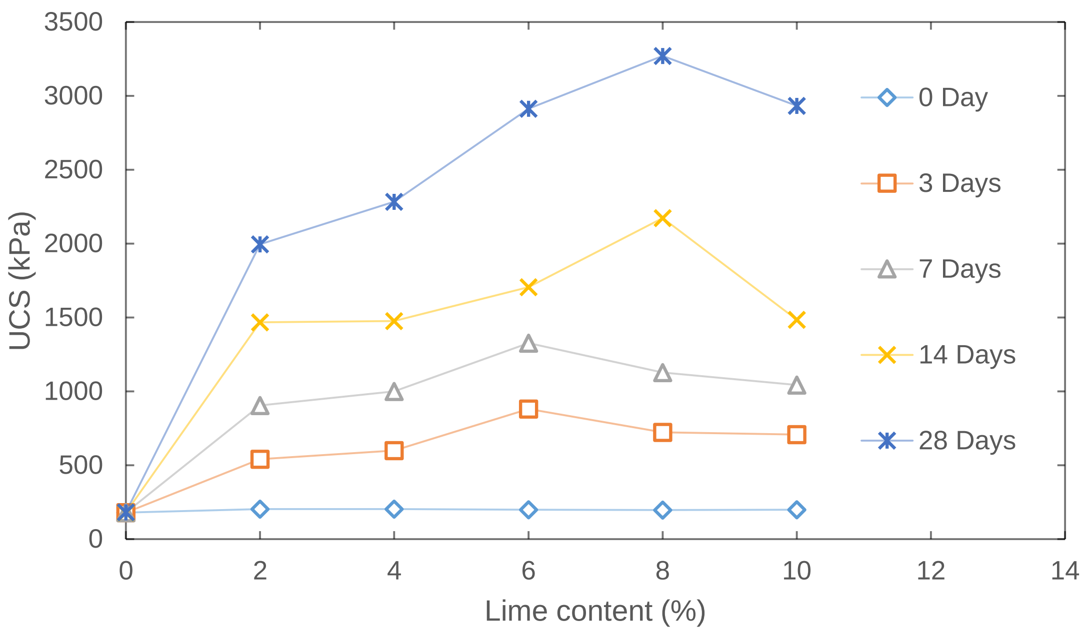

Figure 4.12. Variation in *UCS* for Low Plasticity Clay (*CL*) stabilized with lime at different curing periods

Table 4.6. Unconfined Compressive Strength (kPa) of Lime stabilized Low Plasticity Clay (*CL*) with different curing periods

Sample	Curing Period (days)				
	0	3	7	14	28
CL + 0% lime	178.54	180.50	179.52	180.50	182.47
CL + 2% lime	203.4	540.71	905.14	1466.89	1996.46
CL + 4% lime	202.88	599.86	999.13	1476.13	2283.29
CL + 6% lime	199.41	880.52	1326.75	1705.45	2914.6
CL + 8% lime	197.68	722.78	1128.41	2173.24	3270.46
CL + 10% lime	198.19	708.04	1043.93	1484.43	2934.11

The Unconfined Compressive strength increases rapidly after 14 days curing period for both the soils. Sandy clay achieves maximum unconfined compressive strength of 1001.60 kPa at 6 % lime content for 56 days curing period. Low plasticity clay achieves maximum unconfined compressive strength of 3270.46 kPa at 8 % lime content for 28 days curing period. The higher strength achieved by Low plasticity clay may be attributed to more clay minerals present in the soil to react with lime.

4.4.2 Effect of Fly ash

The increase in fly ash content leads to increase in unconfined compressive strength of soil upto a certain percentage after which there is a decrease in unconfined compressive strength. The unconfined compressive strength of sandy clay (*SC*) and low plasticity clay (*CL*) increased with varying fly ash content for different curing periods as can be seen from Figures 4.13 and 4.14.

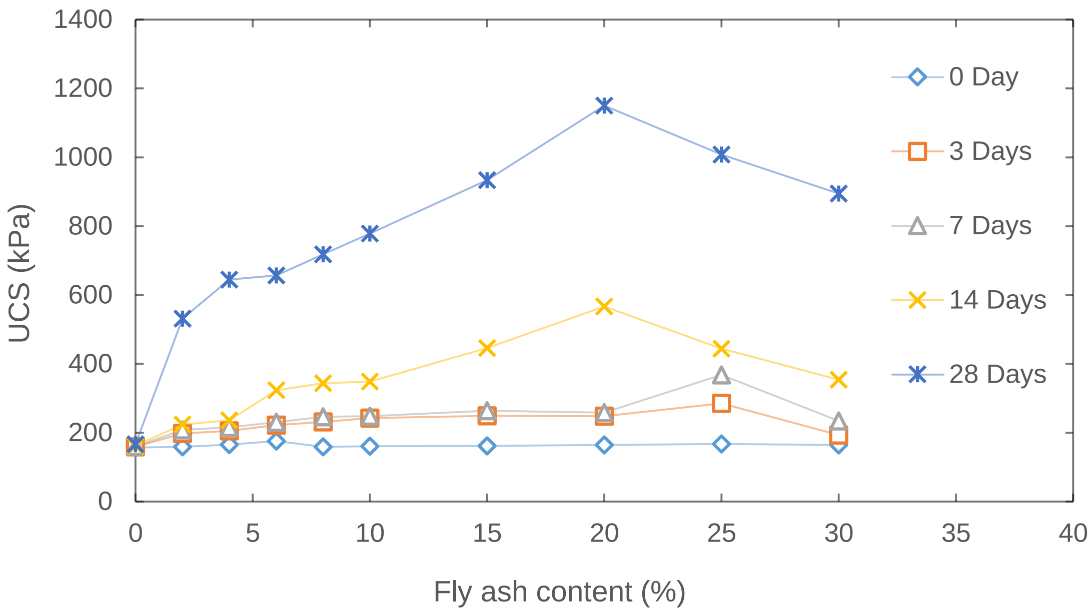

Figure 4.13. Variation in *UCS* for Sandy Clay (*SC*) stabilized with Fly ash at different curing periods

Table 4.7. Unconfined Compressive Strength (kPa) of Fly ash stabilized Sandy Clay (*SC*) with different curing periods.

Sample	Curing Period (days)				
	0	3	7	14	28
SC + 0% Fly ash	156.96	158.92	159.90	161.87	166.57
SC + 2% Fly ash	158.92	198.16	207.97	223.67	531.70
SC + 4% Fly ash	165.79	205.03	215.82	236.42	644.52
SC + 6% Fly ash	175.60	221.71	230.54	323.73	657.27
SC + 8% Fly ash	158.92	231.52	246.23	343.35	718.09
SC + 10% Fly ash	160.88	242.31	248.19	348.26	778.91
SC + 15% Fly ash	161.87	249.17	263.89	446.36	933.91
SC + 20% Fly ash	164.81	248.19	258.00	567.02	1149.73
SC + 25% Fly ash	167.75	285.47	367.88	444.39	1007.49

Sample	Curing Period (days)				
	0	3	7	14	28
SC + 30% Fly ash	164.81	193.26	234.46	354.14	894.67

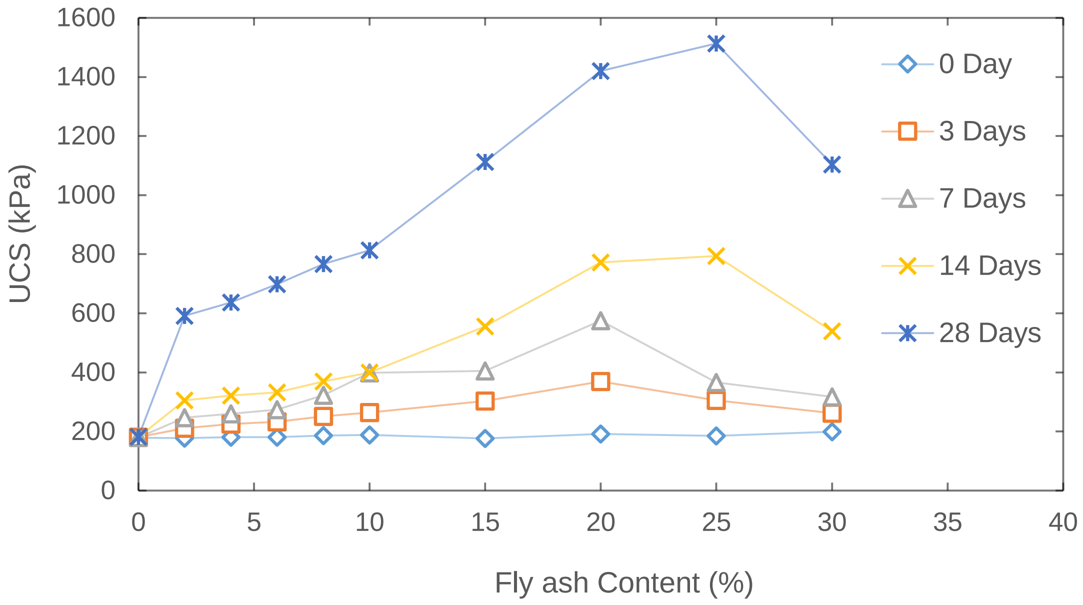

Figure 4.14. Variation in *UCS* for Low Plasticity Clay (*CL*) stabilized with fly ash at different curing period

Table 4.8. Unconfined Compressive Strength (kPa) of Fly ash stabilized Low Plasticity Clay (*CL*) with different curing periods

Sample	Curing Period (days)				
	0	3	7	14	28
CL + 0% Fly ash	178.54	180.50	179.52	180.50	182.47
CL + 2% Fly ash	177.56	210.92	247.21	306.07	591.54
CL + 4% Fly ash	180.50	225.63	259.97	321.77	636.67
CL + 6% Fly ash	180.50	232.50	273.70	332.56	698.47
CL + 8% Fly ash	186.39	251.14	322.75	369.84	767.14

Sample	Curing Period (days)				
	0	3	7	14	28
CL + 10% Fly ash	188.35	263.89	398.29	400.25	813.25
CL + 15% Fly ash	176.58	303.13	405.15	555.25	1112.45
CL + 20% Fly ash	192.28	369.84	574.87	772.05	1419.51
CL + 25% Fly ash	185.41	306.07	365.91	793.63	1512.70
CL + 30% Fly ash	199.14	261.93	317.84	539.55	1103.63

There is rapid gain in strength after 14 days curing period for both the soils. Sandy clay achieves maximum unconfined compressive strength of 1149.73 kPa at 20 % fly ash content for 28 days curing period. Low plasticity clay achieves maximum unconfined compressive strength of 1512.70 kPa at 25 % fly ash content for 28 days curing period. The higher strength achieved by Low plasticity clay may be attributed to more clay minerals present in the soil to react with fly ash.

The decrease in strength with increase in additive content may be explained by the presence of excess lime which neither has appreciable friction nor cohesion serving as lubricant to the soil particles. Also, lime when reacting with soil particles produce cementitious gel that has considerable volume of pores. Hence, with increase in lime content, the soil structure becomes more porous which counteracts the strength gained by cementation. At high lime content, an overall decrease in strength occurs because of excessive formation of gel material.

5. CONCLUSIONS & FUTURE SCOPE OF WORK

An extensive Experimental program was undertaken to achieve the objectives of the present study. Two type of soils were mixed with varying quantities of lime and fly ash. The effect of these additives have been studied on Cation Exchange Capacity (*CEC*), Compaction characteristics and Unconfined Compressive Strength (*UCS*) of both the soil samples. The conclusions drawn from the experimental results obtained are presented in section 5.1.

5.1 Conclusions

- The Cation Exchange Capacity (*CEC*) values decreased more with increase in fly ash content than with increase in lime content.
- The optimum moisture content (*OMC*) increases and maximum dry density (*MDD*) decreases with increased lime content and fly ash content for both sandy clay and low plasticity clay.
- The Optimum Lime Content (*OLC*) for Sandy Clay (*SC*) and low plasticity clay (*CL*) is 6 % and 8 % respectively based on Unconfined Compressive Strength (*UCS*) test.
- Similarly, the optimum fly ash content for Sandy Clay (*SC*) and low plasticity clay (*CL*) is 20 % and 25 % respectively.
- The Unconfined Compressive strength increases with increase in curing period for both soils treated with lime and fly ash.

5.2 Scope for future research work

1. Effect of other additives such as cement, silica fume etc. on Cation Exchange Capacity (*CEC*) and unconfined compressive strength of soils.
2. Effect of additives on Cation Exchange Capacity (*CEC*), Specific Surface Area (*SSA*) and Permeability and their interrelationship.

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